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The Role of Surgeon-Performed Ultrasound in Patients with Possible Cardiac Wounds

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Objective

The authors evaluate surgeon-performed ultrasound in determining the need for operation in patients with possible cardiac wounds.

Background Data

Ultrasound quickly is becoming part of the surgeon's diagnostic armamentarium; however, its role for the patient with penetrating injury is less well-defined. Although accurate for the detection of hemopericardium, the lack of immediate availability of the cardiologist to perform the test may delay the diagnosis, adversely affecting patient outcome. To be an effective diagnostic test in trauma centers, ultrasound must be *immediately* available in the resuscitation area and performed *and* interpreted by *surgeons*.

Methods

Surgeons performed pericardial ultrasound examinations on patients with penetrating truncal wounds but no immediate indication for operation. The subcostal view detected hemopericardium, and patients with positive examinations underwent immediate operation by the *same* surgeon. Vital signs, base deficit, time from examination to operation, operative findings, treatment, and outcome were recorded.

Results

During 13 months, 247 patients had surgeon-performed ultrasound. There were 236 true-negative and 10 true-positive results, and no false-negative or false-positive results; however, the pericardial region could not be visualized in one patient. Sensitivity, specificity, and accuracy were 100%; mean examination time was 0.8 minute (246 patients). Of the ten true-positive examinations, three were hypotensive. The mean time (8 patients) from ultrasound to operation was 12.1 minutes; all survived. Operative findings (site of cardiac wounds) were: left ventricle (4), right ventricle (3), right atrium (2), right atrium/superior vena cava (1), and right atrium/inferior vena cava (1).

Conclusions

Surgeon-performed ultrasound is a rapid and accurate technique for diagnosing hemopericardium. Delay times from admission to operating room are minimized when the surgeon performs the ultrasound examination

The escalation of urban violence, coupled with the development of trauma systems, has resulted in increasing numbers of patients with penetrating thoracic trauma arriving alive at trauma centers.[1,2] Prompt detection and treatment are the critical factors determining optimal patient outcome in patients with these life-threatening injuries, but the insensitivity of physical examination alone, combined with their occult nature, may make rapid recognition difficult.

Whatever the etiology, the diagnosis of pericardial tamponade requires an accurate and rapid test that is immediately available in the resuscitation center. Reliance on signs such as pulsus paradoxus or Beck's triad is misleading because these signs vary with the patient's physiology and therefore, often are absent.[3,4] Although the subxiphoid pericardial window is very accurate for the detection of cardiac injury,[5-7] it is an invasive procedure and may not be indicated in patients in whom there is a low suspicion of a cardiac wound. Ultrasonography, an attractive alternative, is a rapid, sensitive, noninvasive tool for the detection of hemopericardium[8-11]; however, the lack of "around the clock" availability of the cardiologist to perform the test within minutes of the patient's arrival delays the diagnosis and may adversely affect the patient's outcome. For ultrasound to be an effective and practical diagnostic modality in U.S. trauma centers, it must be immediately available in the trauma room and performed and interpreted by the resuscitating surgeon.

The purpose of this study was to evaluate the role of surgeon-performed ultrasound in determining the need for early operative intervention in patients with possible cardiac wounds. We hypothesized that surgeons can reliably perform the subcostal ultrasound examination in patients with penetrating thoracoabdominal injuries and then use the results in the clinical management of these patients.

METHODS

During a 13-month period, ultrasound was evaluated prospectively as the primary modality for the determination of hemopericardium at an urban Level I trauma center. Entrance criteria included patients with penetrating thoracic injuries. Patients who had an admission systolic blood pressure greater than or equal to 100 mmHg were considered normotensive, and those with an admission systolic blood pressure of less than 100 mmHg were considered hypotensive. Patients who presented in extremis (blood pressure unobtainable) with an indication for an emergent median sternotomy or thoracotomy were excluded from the study.

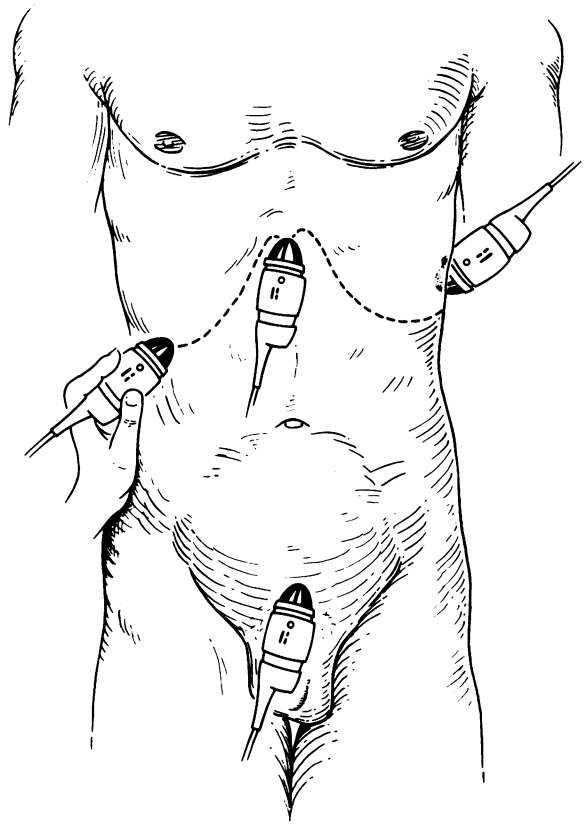

Figure 1. Transducer positions for the Focused Assessment for the Sonographic examination of the Trauma patient.

Training

Attending trauma surgeons, fellows, and surgical residents completed an ultrasound training course conducted by an experienced surgeon-sonographer. Developed for the evaluation of injured patients, the Focused Assessment for the Sonographic examination of the Trauma patient is a 2.5-minute test that detects blood in the pericardial sac and three dependent abdominal areas, assisting the surgeon in rapidly determining the need for operative intervention (Fig. 1).[8-10] The course content included didactics, videotapes, and sample ultrasound images of the Focused Assessment for the Sonographic examination of the Trauma patient with normal and abnormal findings, observation, and practice sessions.

Principles of Pericardial Ultrasound Examination

Of the four ultrasound views including, apical, left and right parasternal, and subcostal, the latter has distinct ad-

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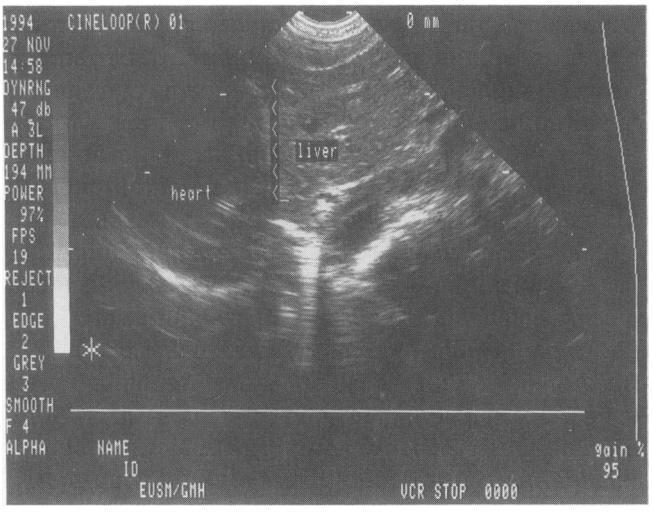

Figure 2. Sagittal or long axis view of normal heart showing pericardium (arrows) as single echogenic line.

vantages in the trauma setting. This view rapidly detects the presence or absence of hemopericardium with the patient in the supine position[11] and can be performed with a transducer that has a broad footprint, as commonly is used for abdominal ultrasound evaluation. The advantage of using the same transducer for both the pericardial and abdominal parts of the Focused Assessment for the Sonographic examination of the Trauma patient is that a sequential survey of the thoracoabdominal area can be performed that expedites the examination process, thereby leading to an earlier diagnosis.

According to the principles of ultrasound physics, blood or fluid is visualized as an anechoic or echolucent dark area on the ultrasound image. In contrast, structures with higher density such as the pericardium appear echogenic as a bright reflecting surface.[12] In the normal heart, the visceral (epicardium) and parietal layers of the pericardium appear as a single echogenic line on the ultrasound image (Fig. 2). When blood accumulates between the pericardial layers, each layer is visualized as a distinct echogenic line with an echolucent zone (blood) between them consistent with hemopericardium[11] (Fig. 3).

Technique

With the patient in the supine position during the secondary survey, all sonograms were performed using an ultrasound machine (Ultramark IV, Advanced Technology Laboratories, Bothwell, WA) with a 3.5-MHz general access transducer owned by the Emory University School of Medicine Department of Surgery and located in the trauma resuscitation room. Using the machine's annotation keys, the medical record number was entered so that the image was labeled appropriately. With the thoracoabdominal area adequately exposed, hypoallergenic water-soluble ultrasound transmission gel was applied to the subxiphoid region, and the examination was conducted according to protocol. The transducer was oriented for sagittal sections, placed in the subxiphoid area, and directed toward the patient's left shoulder. The heart was identified, and the gain setting on the ultrasound machine was adjusted to ensure that blood within the heart appeared echolucent. The subcostal sagittal (long axis) view of the heart was obtained, and the pericardial region was examined for blood.

After a good quality picture was acquired, the automatically timed and dated image was "frozen," printed, and attached to a quality assurance data form. A good quality image was defined as one that showed the correct sagittal section of the heart with adequate visualization of the pericardium to determine the presence or absence of hemopericardium. All ultrasound images were reviewed by the principal investigator (GSR), who noted the quality of the image and the accuracy of the reading.

If results of the ultrasound examination were negative for hemopericardium, the asymptomatic patient was admitted for observation and a repeat physical examination was performed every 12 hours. Patients were followed for a minimum of 24 hours' inpatient observation, through discharge, and as outpatients in clinic. If results of the ultrasound examination were positive, the patient underwent immediate operative intervention by the same surgeon, and operative findings were recorded. If the ultrasound reading was equivocal or a good quality image was unobtainable, a subxiphoid pericardial window was performed or a complete echocardiographic examination was obtained by the cardiologist. Prehospital and admission vital signs, admission base deficit, time from ultrasound examination to operation, operative

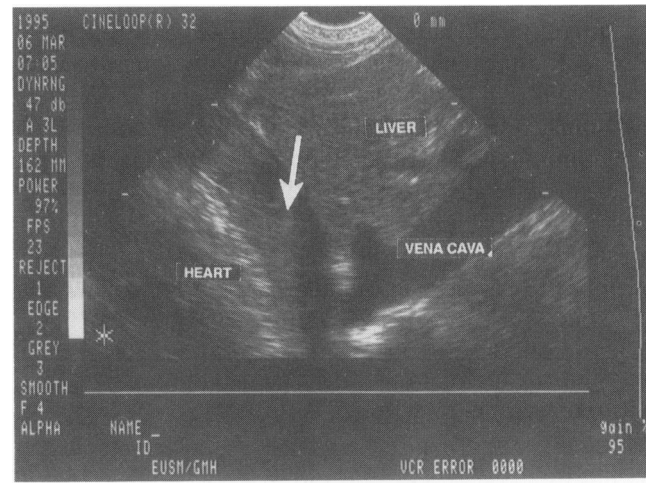

Figure 3. Sagittal or long axis of heart showing separation of pericardial layers by fluid (blood), which appears echolucent.

Table 1. RESULT CATEGORIES: DEFINITIONS

Category	Definition
True-positive	Fluid (blood) identified on the ultrasound image and a subsequent operation that confirmed pericardial tamponade and cardiac injury that required repair.
True-negative	Absence of fluid (blood) on the ultrasound examination and a continued negative physical examination.
False-positive	Fluid (blood) identified on the ultrasound image but a negative exploration, *i.e.*, no injury or blood identified.
False-negative	Absence of fluid (blood) on the ultrasound image, but therapeutic exploration required, that is, injury that required repair.

findings, treatment, and outcome were recorded. Results were categorized as true-positive, true-negative, false-positive, and false-negative (Table 1).

RESULTS

During a 13-month period, 247 consecutive patients (121 gun shot wounds, 126 stab wounds) with penetrating chest wounds underwent focused ultrasound examinations of the pericardial region by surgeon sonographers. The surgeon's ability to accurately perform the ultrasound examination and interpret the film was confirmed by the principal investigator, who agreed with the interpretations of all the studies. Most of the patients were males (86%), with a mean age of 31 years (range, 16–79 years), and the mean Injury Severity Score was 12. The mean examination time was only 0.8 minute. Only one patient died of multisystem organ dysfunction 2 weeks after repair of multiple intraabdominal and thoracic injuries. There were 236 (95.5%) true-negative and 10 true-positive results, and no false-negative or false-positive results. However, the pericardial region could not be visualized in one patient. For the 246 patients who had pericardial ultrasound examinations performed by the surgeons, the sensitivity, specificity, and accuracy were 100%.

For the ten patients with true-positive results, the means for Revised Trauma Score, Injury Severity Score, and hospital length of stay were 7.08, 27 (range, 25–34), and 13.5 days, respectively (Table 2). The mean time (available in 8 patients) from ultrasound to operation was 12.1 minutes. Admission base deficit was available in only seven of these patients and ranged from −3.2 to −21.6; however, patient numbers were too few to achieve statistical correlation with admission blood pressure or injury. Operative findings for all ten patients included wounds to the left ventricle (4), right ventricle (3), right atrium (2), right atrium/superior vena cava (1), and right atrium/inferior vena cava (1). All ten patients survived and continue to do well.

Three of the ten patients (gun shot wounds) had an admission systolic blood pressure of less than 90 mmHg, one of whom manifested pulsus paradoxus. The surgeon-performed ultrasound examinations successfully detected hemopericardium in all three patients, and pericardial tamponade was confirmed at operation.

The other seven patients (4 gun shot wounds, 3 stab wounds) with true-positive examination results were normotensive on admission and had no clinical signs of tamponade. Because this diagnostic modality was new to the trauma team, four of these asymptomatic patients underwent subxiphoid pericardial windows to confirm the presence of tamponade before performing the thoracic incisions. The surgical team was unable to obtain an adequate subcostal cardiac view in one patient and therefore, a formal echocardiographic examination was performed by the cardiologist 125 minutes after the patient's arrival. Once hemopericardium was diagnosed, the patient was taken to the operating room where a small epicardial laceration of the right ventricle was repaired.

DISCUSSION

As a noninvasive and sensitive diagnostic modality, ultrasound quickly is becoming an integral part of the surgeon's diagnostic armamentarium[8,9,13–15]; however, its role in the evaluation of the patient with penetrating injury is less well-defined.[8,9] Considering the many occult and potentially lethal injuries associated with penetrating thoracic trauma, ultrasound imaging is especially useful because it allows a noninvasive, bedside diagnosis to be made rapidly with the additional advantage of being easily repeatable. Such a test to promptly detect hemopericardium is valuable because this finding in an otherwise asymptomatic patient (7 of 10 patients in this study) with a penetrating thoracic injury will dramatically shorten the time to operative intervention.

As anticipated, most of the patients in the study had true-negative examination results. This finding is similar to the results of other studies, including large numbers of patients with penetrating thoracic wounds.[16–20] Therefore, ultrasound, a noninvasive tool, is valued not only for its sensitivity, but also for its potential cost-effectiveness. When the pericardial ultrasound is performed by the surgeon in the resuscitation area, the cardiologist's

Table 2. PATIENTS WITH TRUE-POSITIVE EXAMINATION RESULTS

Patient	Admission Blood Pressure (mmHg)	Base Deficit	Time (min) US to OR	Operative Findings
1	100	Not done	25	Left ventricle ×2
2	100	Not done	8	Right atrium/SVC ×2
3	160	−3.2	9	Left ventricle
4	100	−13.6	5	Right ventricle
5	100	−7.4	Unknown	Right atrium/IVC
6	110	Not done	20	Left ventricle
7	130	−6.5	10	Right ventricle
8	92	−9.9	10	Right atrium
9	80	−21.6	10	Right and left ventricle
10	80	−15.0	Unknown	Right atrium ×2

US = ultrasound; OR = operating room; SVC = superior vena cava; IVC = inferior vena cava.

fee is eliminated and items such as central venous catheters are used less frequently. This saves time and money and decreases patient morbidity.

Seven of the patients with true-positive examination results were normotensive on admission, including one with a stab wound in the upper outer quadrant of her left breast outside the area of cardiac proximity[21] (Fig. 4). This patient underscores the value of ultrasound as an accurate screening modality for hemopericardium because, based on the location of her wound and vital signs on admission, it is unlikely that she would have undergone an early pericardial window or measurement of central venous pressure. Although such patients eventually become symptomatic, avoidance of physiologic deterioration by early diagnosis and treatment considerably decreases patient morbidity.[22] Advantages of decreasing delay times to the operating room for symptomatic patients with penetrating truncal injuries have been advocated by many,[23,24] most recently underscored by Ingram and colleagues.[25] They observed that some normotensive patients with penetrating truncal wounds have serious occult injuries and therefore, recommend that these patients undergo resuscitation in the operating room or spend minimal time (< 10 minutes) in the emergency department.[25] The use of a rapid and accurate modality in the hands of the surgeon who controls the resuscitation is an important way to decrease that time spent in the emergency department. Real-time ultrasound imaging provides instantaneous results of the examination, and thus, decisions regarding the patient's management are made earlier. In this study, patients with potentially lethal cardiac wounds, 70% of whom were asymptomatic, arrived in the operating room within 14 minutes (mean) of the ultrasound examination.

Making a diagnosis of hemopericardium is even more important for those patients who present with hypotension because the pericardial ultrasound examination rapidly documents the source and shortens the interval to definitive treatment. Additionally, for patients with multiple penetrating truncal wounds who are hypotensive on admission, the source of hypotension may be uncertain, as was the case in one of our patients. A rapid ultrasound examination to detect hemopericardium, allows the surgeon to prioritize treatment of the cardiac injury rather than perform an unnecessary celiotomy.

In other studies evaluating the use of ultrasound in the

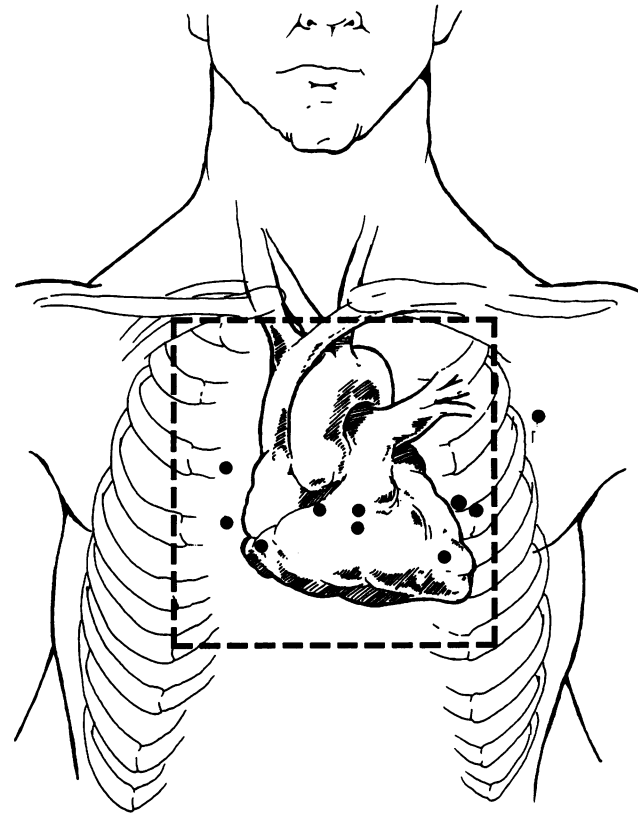

Figure 4. Cardiac proximity diagram indicating entrance sites for penetrating injuries.

trauma setting, the learning curve had an impact on the sensitivity and specificity of the results.[8,9] However, in this study, the surgeon sonographers were instructed that visualization of the echogenic pericardium was an essential component of the examination. When a good quality ultrasound image was unobtainable, the team followed the protocol to perform a subxiphoid pericardial window or obtain an echocardiographic examination by the cardiologist.

The subcostal image usually is not difficult to obtain, even with the general access transducer. Nevertheless, a severe chest wall injury, a very narrow subcostal area, subcutaneous emphysema, or morbid obesity can prevent a satisfactory examination.[12] Both of the latter conditions are associated with poor imaging because air and fat reflect the sound beam too strongly and prevent penetration into the target organ.[11,12] Although the one patient in this study in whom the surgical team was unable to obtain an adequate ultrasound image did not have any of these conditions, the use of a cardiac access transducer with a narrow footprint or transesophageal echocardiography[26,27] may have improved cardiac imaging and led to an earlier diagnosis. Although accurate, these modalities are more expensive, time consuming, and not indicated in the majority of trauma patients. Additionally, continuous recording or videotaping of the study may have provided more information to identify correctable factors that adversely affected the examination. The purpose of videotaping the examination is that the dynamic real-time image provides more information for the surgeon reviewing the images, thereby increasing the confidence level associated with each observation.[12] Although advantageous, remembering to videotape the examination routinely was difficult for the trauma team, especially when a positive examination was noted because the tendency was to go directly to the operating room without delay.

Concern regarding the accuracy of ultrasound in patients with penetrating chest wounds has been expressed by some authors.[28,29] In Bolton's study, a subxiphoid pericardial window was more accurate when compared with echocardiography in detecting intrapericardial injuries.[28] The two patients in that study with negative ultrasound examinations were hypotensive on admission and had proximity wounds.[21,28] More recently, Meyer and colleagues cautioned that a false-negative reading may occur in patients with large hemothoraces that obscure a small hemopericardium.[29] In our study, four of the ten patients with pericardial tamponade had hemothoraces, and hemopericardium was identified easily on the initial pericardial ultrasound examination. Using the Focused Assessment for the Sonographic examination of the Trauma patient, the surgeon can easily detect a hemothorax before obtaining a chest radiograph,[9] and repeat the pericardial ultrasound examination after the insertion of a thoracostomy tube to drain the hemothorax. Additionally, the use of other physiologic parameters such as the base deficit may suggest abnormal perfusion and prompt concern regarding a cardiac injury. Instead of attempting to delineate the areas in which the pericardial ultrasound examination may be compromised, clinicians should understand that it is a diagnostic adjunct and exercise the same sound clinical judgment they do with other diagnostic modalities.[9,30]

A potential weakness of the study was the follow-up of only approximately 50% of the study patients in clinic. Grady Memorial Hospital is the only Level I trauma center within Atlanta, Georgia, and patients with prior treatment for a penetrating thoracic injury would most commonly return if a complication developed. To our knowledge, no injury was missed.

Notwithstanding these issues, the surgeons' results in this study compared favorably with those reported by cardiologists and emergency physicians.[31-36] Although these reports lend credence to the value of ultrasound for the diagnosis of hemopericardium, the use of this modality by the resuscitating surgeon has added advantages. Most important, there is immediate additional information for patient evaluation without the inevitable delays of paging the cardiologist, moving the ultrasound machine into the trauma room, and awaiting the performance and interpretation of the test. Furthermore, the use of pericardial ultrasound by the surgeon is well suited to the trauma setting because of the following unique qualities:[8] 1) *noninvasvive*—allowing a benign way to screen for hemopericardium; 2) *repeatable*—important for high-risk patients who would benefit from another examination; 3) *portable*—bedside evaluation obviates the need for transporting the patient from the protected resuscitation area; 4) *rapid*—an early diagnosis is advantageous not only for the patient with a positive examination result, but also for the one with a negative result, because that patient can be moved from the resuscitation area sooner and improve resource allocation; and 5) *cost effective*—if compared with a subxiphoid pericardial window, the cost of the ultrasound examination performed by the resuscitating surgeon is modest (Table 3). In addition to these positive qualities, ultrasound requires no patient preparation and has a high degree of patient compliance because as it is virtually painless.

In this study, surgeons successfully performed and interpreted a limited pericardial ultrasound examination and then used the results of the test in the decision matrix for patient care. Furthermore, this study showed that in the hands of surgeons, pericardial ultrasound is an accurate and rapid test for detecting hemopericardium. Based on our data we conclude that 1) a focused ultrasound examination of the pericardial region performed by the

Table 3. COMPARISON OF ULTRASOUND, SUBXIPHOID PERICARDIAL WINDOW, AND CENTRAL VENOUS PRESSURE MEASUREMENT

	Ultrasound	SPW	CVP
Cost estimate	Cost of machine*	$2,500	$150
Time (min)	0.8	30–40	10
Accuracy	98–100%	98–100%	<50%

SPW = subxiphoid pericardial window; CVP = central venous pressure measurement.
* One time investment. Cost of ultrasound system was $33,200.

surgeon is a rapid and accurate technique for the diagnosis of hemopericardium and subclinical cardiac tamponade; and 2) delay times from admission to operating room are minimized by having the surgeon perform the ultrasound examination in patients with penetrating thoracic wounds.

We recommend that surgeons become proficient in using this specific ultrasound technique and that general surgery program directors incorporate focused ultrasound instruction into residents' training.

Acknowledgments

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Discussion

DR. JOSEPH A. MOYLAN (Miami, Florida): Thank you, Dr. Thompson, Dr. Copeland. I am delighted to discuss this paper and to congratulate Dr. Rozycki and Dr. Feliciano and their colleagues on what I think is going to be one of the key diagnostic approaches to blunt and abdominal truncal trauma. These surgeons have described a very large series of chest injuries in a 13-month period with an incidence of actual cardiac injury of 5%.

I think it illustrates the importance of the surgeon as the leader in trauma management. I think we have abdicated to many others, the radiologists, the cardiologists, some of our roles, and I am delighted to see these authors emphasize what I would call an optimal trauma management goal.

It evaluates an infrequent injury, only 5% of their chest trauma, that has an extremely high morbidity and mortality when diagnosis is delayed. And that outcome is key to early surgical intervention. Their approach is effective and accurate by their dreaded hundred, hundred, hundred. It is cost effective and does not involve other diagnostic procedures, such as computed tomography, outside of the resuscitation room, and it clearly prevents delay in management because of their rapid intervention.

I have a couple of questions I would like to ask them, because we, too, at the Ryder Trauma Center at the University of Miami share their enthusiasm for surgeon-performed ultrasound and also agree that it is a key part of resident and fellow training.

Grace and David, were you able to quantitate how much blood you were able to see? We recently had a false-negative in the chest in which the first ultrasound did not show blood, but an hour later, we were able to diagnose. But it was yet less than 50 mL. What is the smallest amount of blood you have seen?

A comment: The combatants in Atlanta seem to be less accurate in hitting the target zone than those in Miami. Our incidence of actual injuries is much higher than 5%. Tell us, of those you evaluated, how many were really in the target zone of those 247 injuries?

Dr. Rozycki clearly is one of premier surgeon ultrasound implementers in the United States. Can you define for us what you think the training curve is going to be in terms of training other trauma surgeons and residents? Are you planning to validate this very effective technique in those less skilled than yourself?

In conclusion, I think this is an outstanding study. When you have chance to read the manuscript, it is very clearly outlined. I appreciate the opportunity and congratulate the authors.

Thank you.

DR. TIMOTHY C. FABIAN (Memphis, Tennessee): Dr Thompson, Dr. Copeland, Members, and Guests. I also would like to compliment the authors on both an excellent manuscript as well as a very fine presentation by David.

I believe evaluation for potential cardiac will end up probably being one of the most, if not the most important application for ultrasound in the trauma setting. It is really sort of difficult to be critical of this work and, therefore, I will restrain my natural instincts and simply ask Dr. Rozycki a few questions.

First, it is remarkable and a testimony to your didactic training program that over 13 months with 247 patients there must have been a number of surgeon sonographers. And there was 100% accuracy. How many sonographers were involved with these 247 examinations?

Second, how many patients had cardiac wounds during this 13-month interval who did not undergo ultrasound examination, so we can get a feel for the overall impact of ultrasound in the totality of management of penetrating cardiac trauma?

Third, how many of these ten positive patients also underwent laparotomy? Further, how do you sequence laparotomy and thoracotomy in these selected patients who are relatively hemodynamically stable? And what is your choice of chest incision? Are you afraid to contaminate the pericardial cavity with sternotomy or not?

You mentioned that 70% were asymptomatic, although there were base deficits present in all patients in whom that test was performed, some being profound, with the mean base deficit being −11.

The final question, then, is how did those deficits compare with the 237 patients with negative ultrasound? Was this a discriminating finding?

I greatly enjoyed this work. It is excellent, and I think ultrasound is going to have an important place in trauma management in the future. And certainly, Dr. Rozycki has been one of the champions. I thank the Association for the privilege of discussing this paper.

DR. KIMBALL I. MAULL (Chicago, Illinois): Dr. Thompson, Dr. Copeland, Members, and Guests. I rise simply to congratulate the authors for providing the leadership to bring this diagnostic modality into the forefront of trauma diagnosis and management.

We have very little experience with this technique at Loyola University, Chicago, but there is an old saying that you should not be the first to adopt a new technique or the last to give up the old. We are anxious to participate in this new diagnostic approach to the patient with multiple injuries.

Grace, I have a little pride of ownership. Dr. Rozycki was one of my residents at the University of Tennessee. I congratu-